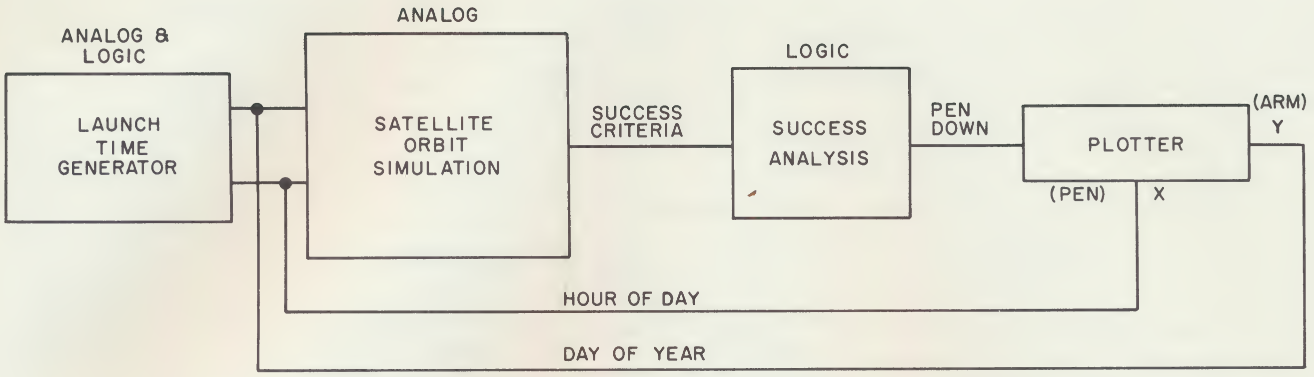

Figure 5: Launch Window Computation

to position the plotter for recording the Launch Window. The success criteria generated by the orbit simulation is analyzed by the logic elements to control the pen of the plotter.

The sequence of operation of the problem is to set the day of the year at some arbitrary point, let us assume January 1, and the hour of the day at midnight. The analog program is then put into operate by a logical command and, if the launch is successful, the plotter pen is lowered. The hour of the day is then advanced automatically by a small increment and a new run made. This procedure is then repeated until a failure is sensed which causes the plotter pen to be raised. In this way, a plot of those particular times during the day which will result in successful launches is obtained. When one 24-hour period is completed, the day of the year was advanced by one and a new plot obtained. The resultant plot indicates the Launch Windows for an entire year.

The automation provided by the digital logic provided an extremely efficient operation of the problem and provided the results in a form most meaningful to the analyst. When compared to the estimated time for computation of the Launch Windows on a digital computer, the economic savings by using the hybrid system was over 40 to 1.

Aircraft Adaptive Control

A second application of patchable logic with an analog computer is for simulation of an adaptive control system for an aircraft.[2] The adaptive control system employs an on-board computer to predict the future performance of the aircraft and, in conjunction with an optimization scheme, to determine the optimum control parameters. The overall configuration of this simulation is shown in Figure 6. Two mathematical models of the aircraft and its control system are implemented on the analog computer, one to simulate the real time motion of the aircraft and the second to predict at high speed the future performance of the aircraft based on the present state variables of the real time model and the present control input conditions. In addition, a reference model is required which produces an output which represents the desired aircraft response. The control optimization is performed by comparing the high speed model to the reference model, computing an index of performance, and feeding this error value back to adjust parameters in the high speed controller to obtain the best response. When the optimum control parameters have been determined, they are sent to the real time controller.

In addition to this basic control loop, it is necessary to update the parameters in the high speed aircraft model to compensate for changes in the environmental conditions of the aircraft. This effect is simulated by introducing noise into the real time aircraft simulation. The changes in parameter values (parameter tracking) are determined analytically as a function of the present state and control variables.

In this simulation, the analog computer solves the equations for the low speed and high speed models of the aircraft and its control, the reference model generation, and the parameter tracking. The patchable logic is used to control the optimization process including the modes of the high speed model, evaluation of the error gradients as a function of parameter changes, and implementation of the optimum control parameters. This simulation indicates the efficient utilization of the high speed of the analog computer which is made possible by the addition of patchable logic.

Reaction Jet Control of a Space Vehicle

A third application of this basic hybrid computing capability is the simulation of a space vehicle with a reaction jet control system.[3] In this case, the

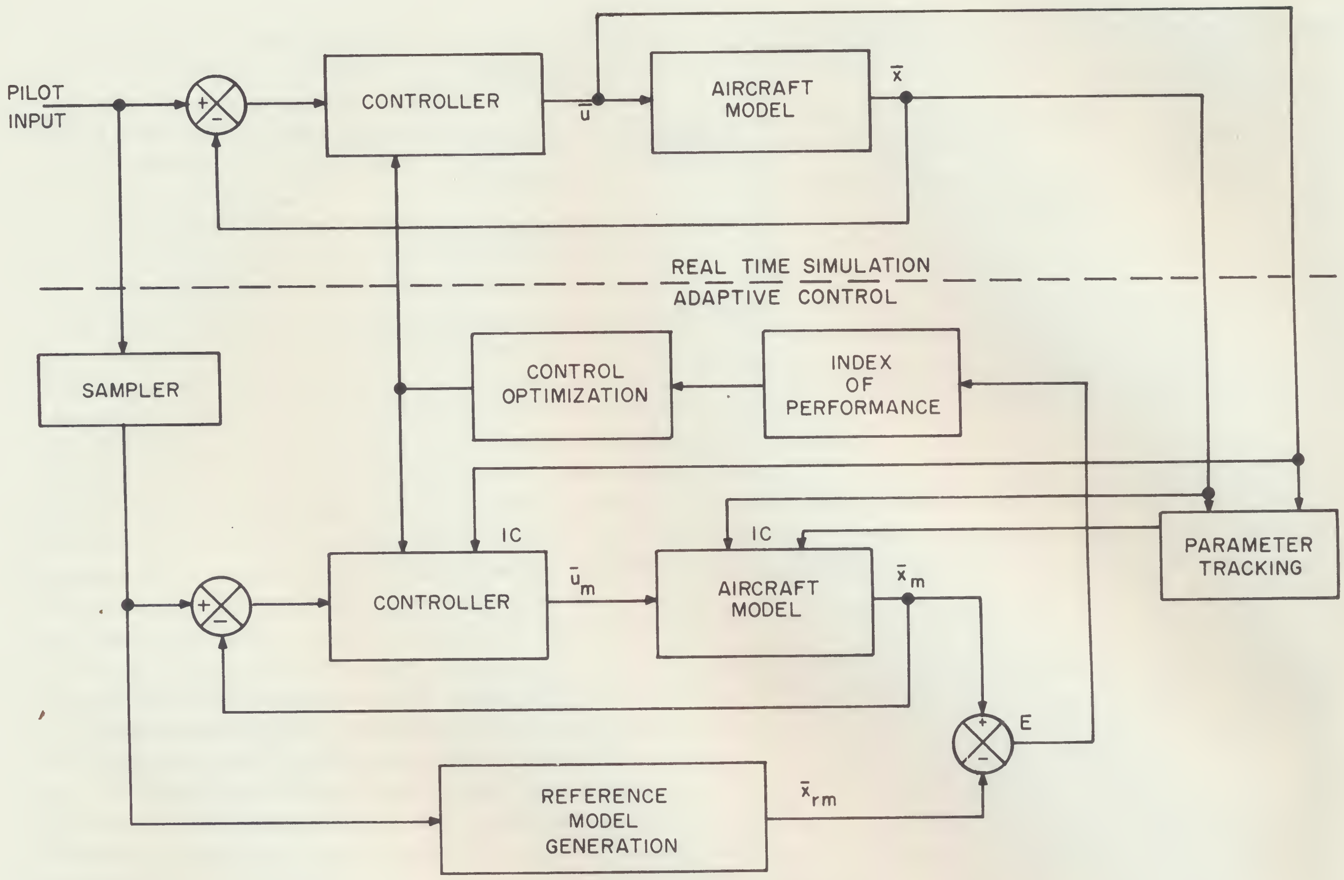

Figure 6: Aircraft Adaptive Control Simulation

requirement is to simulate both the attitude of the vehicle and the pulse jet control system which is essentially digital in nature. A block diagram of the overall simulation is shown in Figure 7. The vehicle attitude equations are solved on the analog computer to produce attitude angles which are compared to the commanded values. These error terms are then combined with the angular rates, which provide the necessary damping, to obtain the error functions for use in the digital controller. These signals are quantized to obtain logical levels which represent both the sign and the magnitude of the errors. The logic levels are then used in conjunction with the errors to produce pulses with a width proportional to the error signals. Since a typical space vehicle has eight jets to control the three degrees of freedom in attitude, these pulses must be translated from commands in attitude angles to specific commands to the jets. The jet command signals then drive circuits which produce the equivalent moments for the vehicle simulation.

Since the problem must be run much faster than real time, the pulse widths which must be simulated are as narrow as 50-100, which demands the use of parallel logic rather than the digital computer for this application.

EKG Data Analysis

The first class of combined hybrid applications is characterized by an open loop transfer of data from the analog to digital computers. A specific example of this type of application is the analysis of electrocardiographic data to detect abnormalities.[4] The original data from three orthogonal sensors on the body is available on magnetic tape. The three data processing functions performed by the hybrid computer are combining the three channels into a single EKG vector magnitude, smoothing of this resultant waveform to eliminate baseline and high frequency variations, and analysis of this average waveform to determine peak amplitudes and periods of occurrence of the various pulses in the cardiac waveform.

An overall block diagram of the hybrid computer program for this application is shown in Figure 8. The raw data from magnetic tape is first amplified and enters an analog program to compute the vector magnitude. Both analog and patchable logic components are then used to reset the baseline of the waveform to eliminate long term drift in the signal. This data then branches in two directions, first to a small program to compute the mean and mean

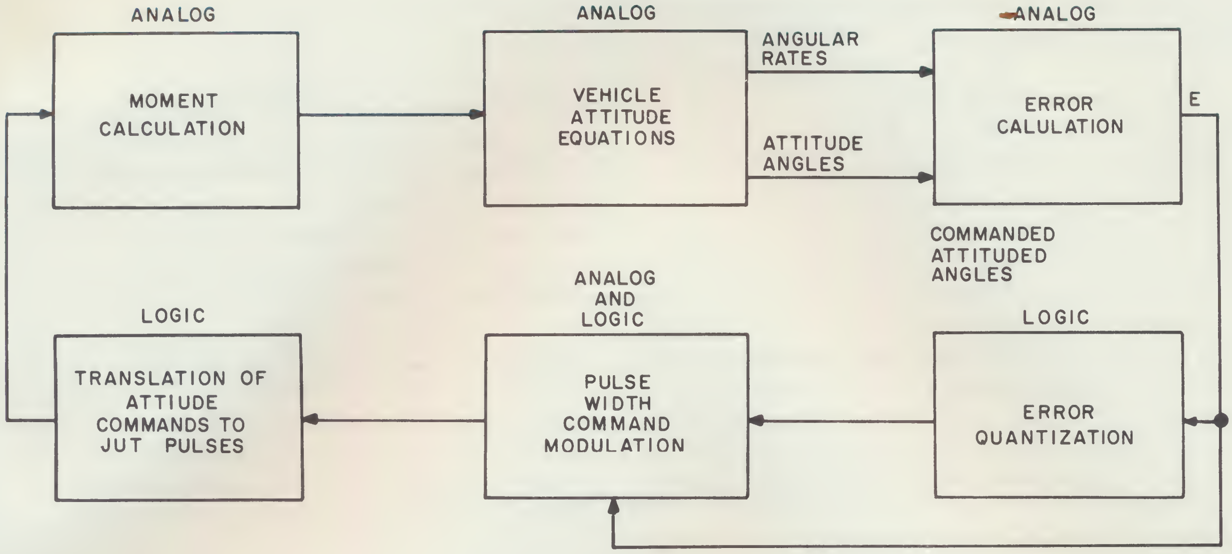

Figure 7: Diagram of Reaction Jet Control Simulation

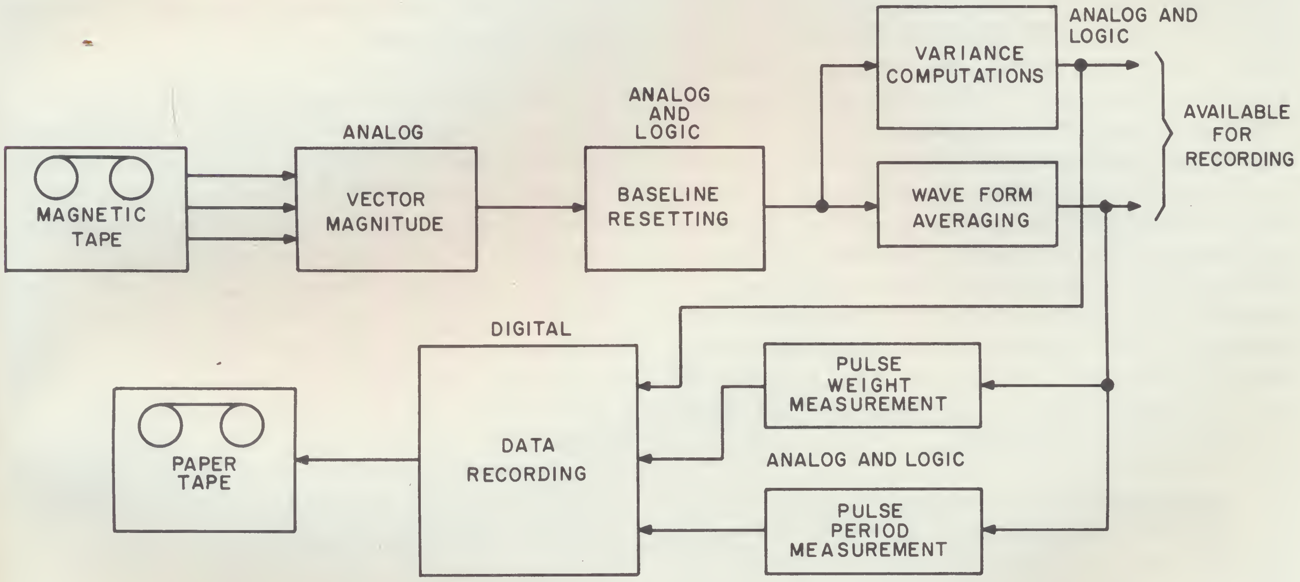

Figure 8: EKG Data Reduction Program

square time interval between pulses within and between heartbeats, and second, through conversion equipment to the digital computer where the waveforms are accumulated and averaged. This data may be recorded for future processing if desired. However, once the complete record for a patient has been processed, the input magnetic tape can be automatically stopped and the digital computer can proceed to output the averaged waveform to the analog to obtain measurements of the pulse heights and periods.

This data is then fed back to the digital computer in conjunction with the data on the variance of the individual heartbeats to be recorded on paper tape (digital magnetic tape could be used). This reduced data is then available for comprehensive analysis by a digital computer to relate the EKG characteristics to particular diseases.

Tubular Reactor Simulation

The first class of applications for closed loop hybrid computation is the solution of partial differential equations. One specific example of a successful hybrid solution of a set of partial differential equations is in the simulation of a tubular reactor.[5] The basic requirement of this study was to design a control system to maintain a constant output product flow rate. The scheme for the solution of

Aerospace Vehicle Re-Entry

As mentioned earlier, one of the major uses of hybrid computation has been in the combined simulation of an aerospace vehicle. One example of this type of problem is the simulation of a space vehicle re-entering the atmosphere under control of a temperature rate sensing system.[7] In this type of control system, temperature sensors are placed on the wing-tips and nose of the vehicle to sense those points which are subject to the greatest aerodynamic heating during re-entry. The control system operates on the rate of change in the temperature of these points to control the attitude of the vehicle to insure safe limits in the skin temperature peaks. This control will override the guidance system commands if the integrity of the vehicle is in danger.

An overall block diagram of this simulation is shown in Figure 11. As in all simulations of this type, the translational equations of motion are solved on the digital computer for accuracy and the attitude equations are handled on the analog computer due to the lower accuracy requirements and higher frequencies.

The digital computer is also used to simulate the guidance system and the temperature sensors since these are related only to the lower frequency variables generated from the translational equations. In addition, the digital computer is used to compute the aerodynamic force and moment coefficients which include four functions of one variable and four functions of two variables using stored tables in the digital memory. The patchable logic is used to simulate the reaction jet control of the vehicle attitude as a result of commands from the temperature rate flight control program.

It should be noted that a complete system simulation such as this encompasses a number of the standard operations listed in the basic functions. This simulation was very successful and an efficiency of at least 20 to 1 over all digital computation was realized.

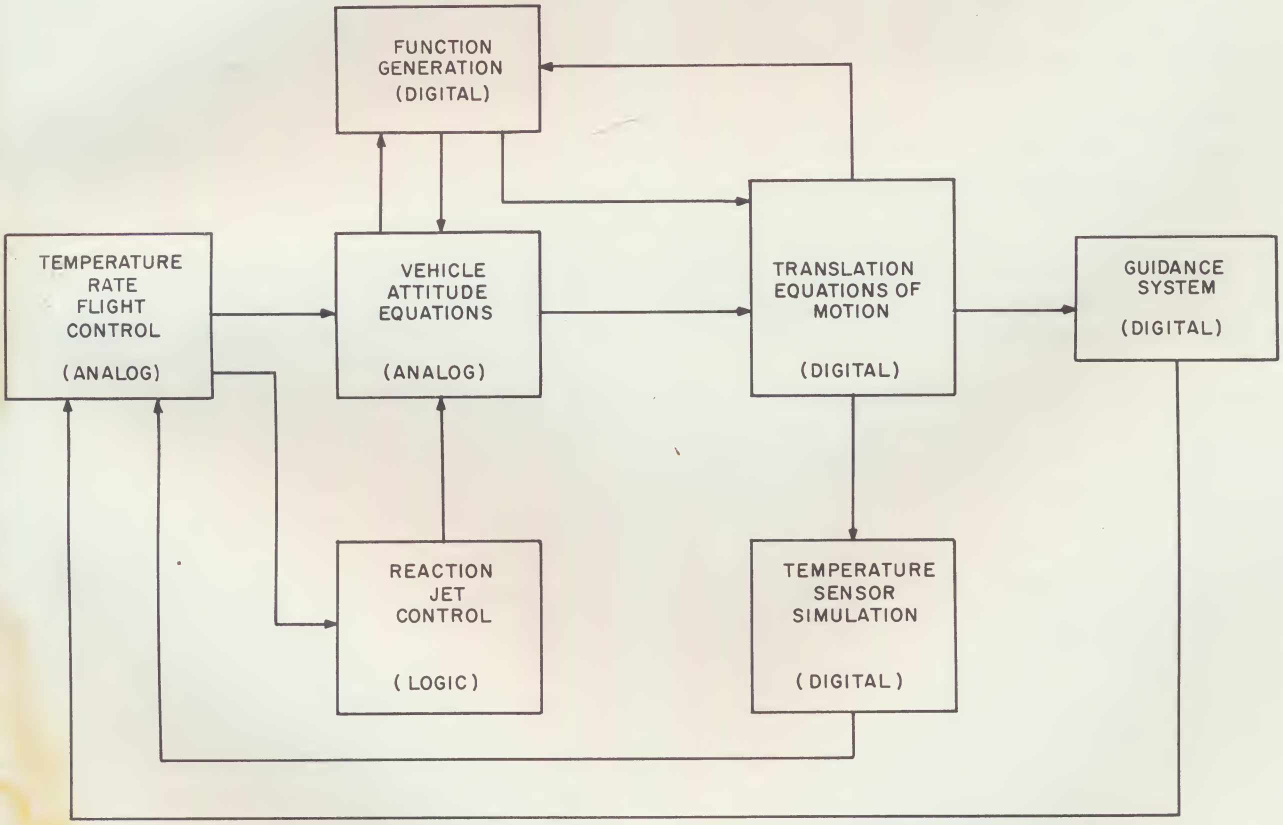

Figure 11. Space Vehicle Re-Entry Simulation

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